

A Multi-Domain Magnetic Passive Aerosol Sampler for Measuring Particle Penetration Through Personal Protective Ensembles

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Introduction

- Current testing methods for particle penetration through protective ensembles is mainly based on active filtration principles, which may not accurately reflect actual penetration.
- New performance specifications for commercial protective ensembles require Man-In-Simulant Testing (MIST) to measure leakage at up to 40 body locations. (Fig. 1)
- Conventional passive devices are not ideal for this application because of low collection efficiency resulting in an unacceptably long testing time.

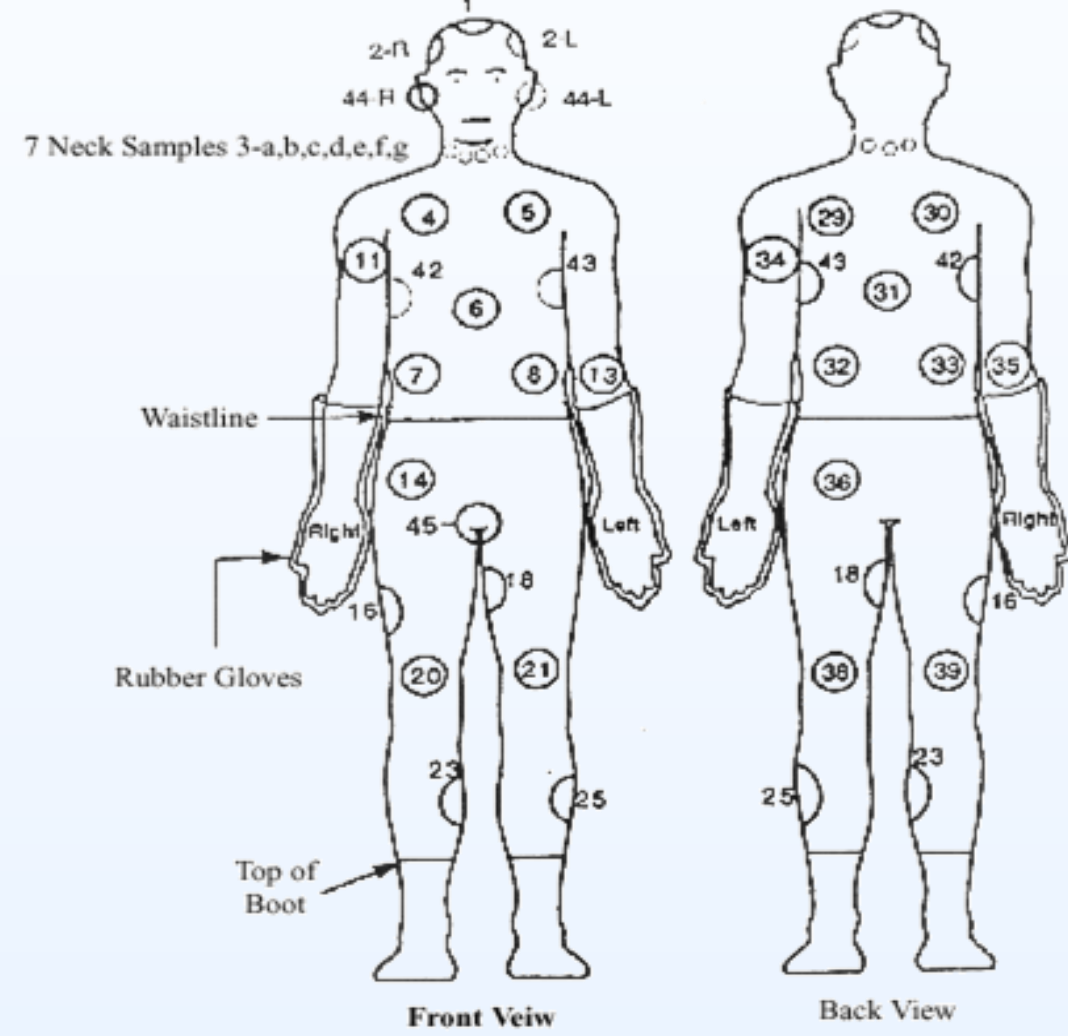


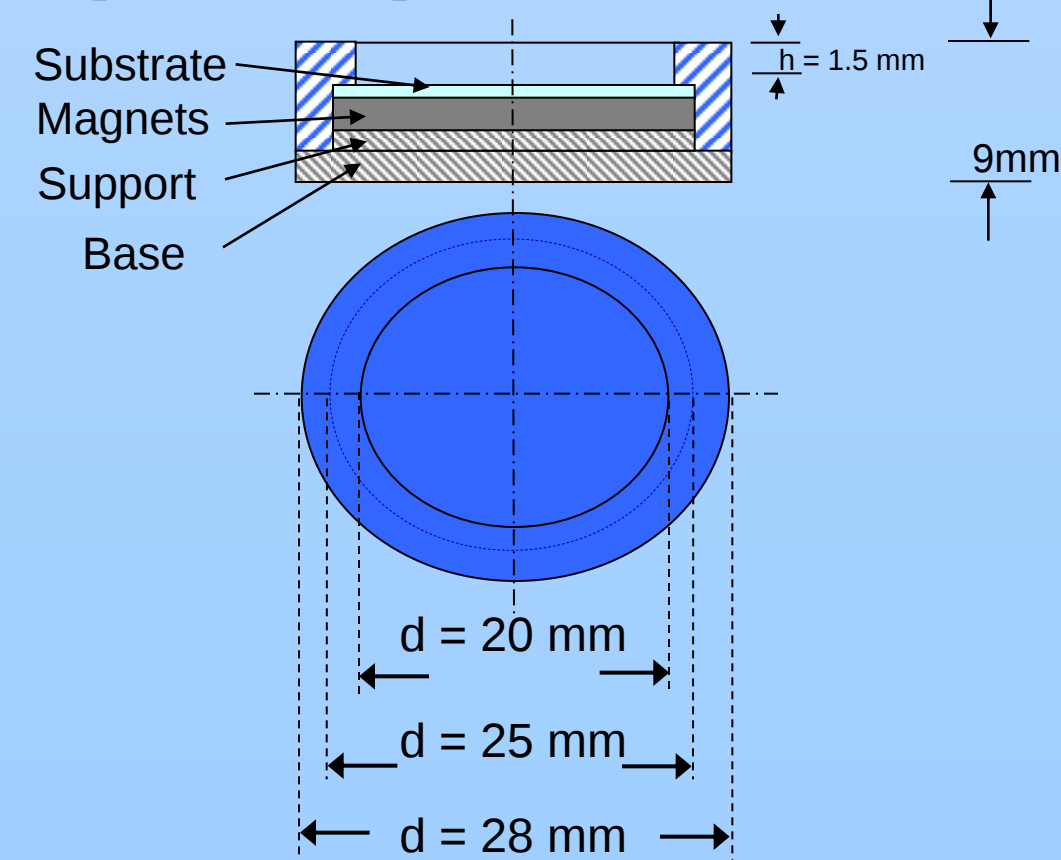
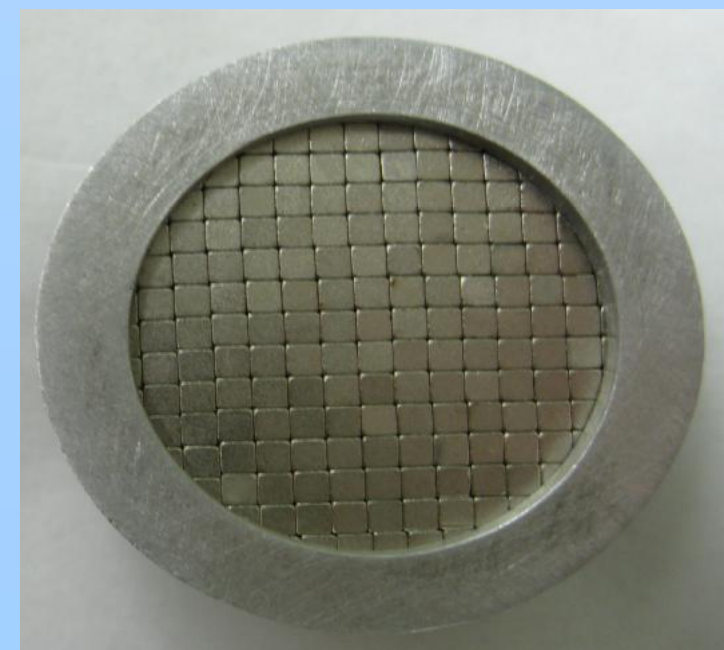
Fig 1. Sampler Locations During a MIST

Objectives

- Develop a magnetic passive aerosol sampler (MPAS) for measuring particle penetration through protective clothing.
- Develop appropriate procedures for evaluating the collection efficiency and optimizing the sampling time of the MPAS for application in MIST.
- Investigate the performance of the MPAS under different operational conditions, including different sampling time, particle sizes, wind velocities, and sampler orientations.
- Establish a deposition velocity model for the sampler to characterize particle concentration in air.

Methods and Materials

1. Development of a Multi-Domain Magnetic Passive Aerosol Sampler (MPAS)



a. multi-domain magnetic passive sampler with 186 magnets (1.5 x1.5 mm) b. dimension of the MPAS (drawing not to scale)

Fig 2. Prototype of the Multi-Domain Passive Aerosol Sampler (MPAS)

2. Generation of Monodisperse Iron (II, III) Oxide Particles as the Challenge Aerosols

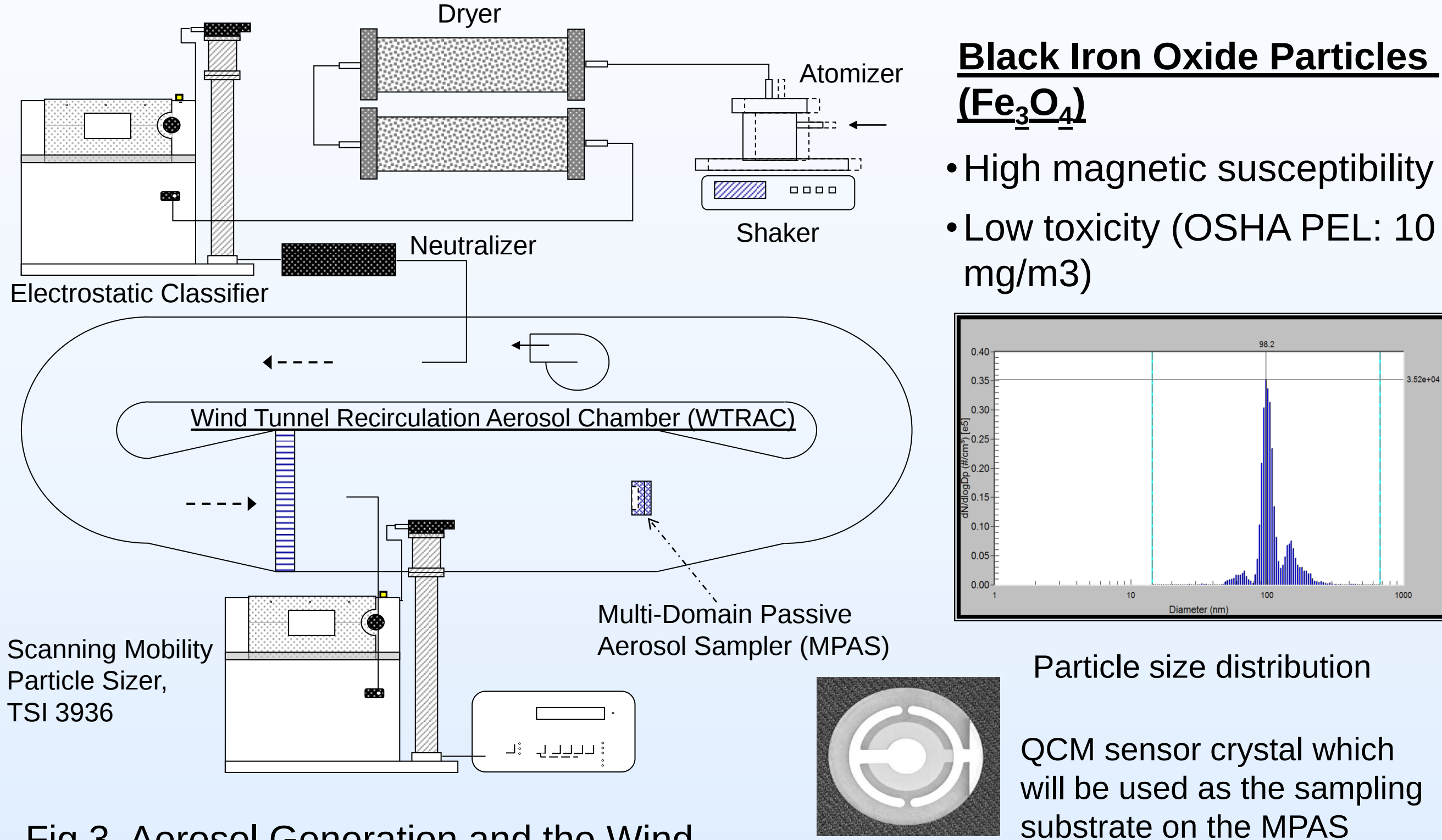
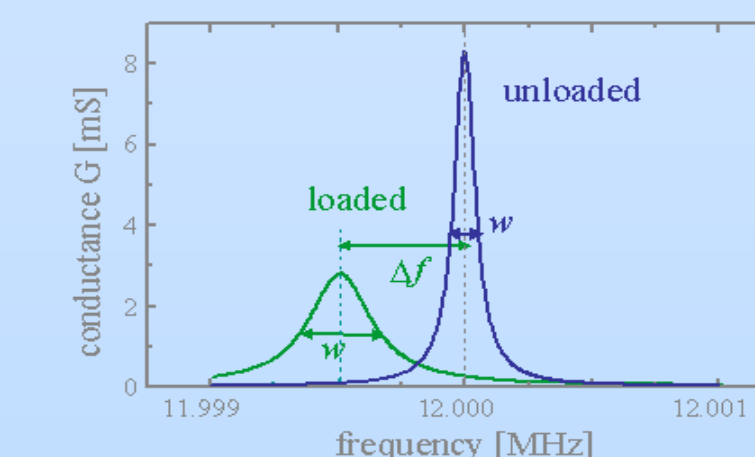
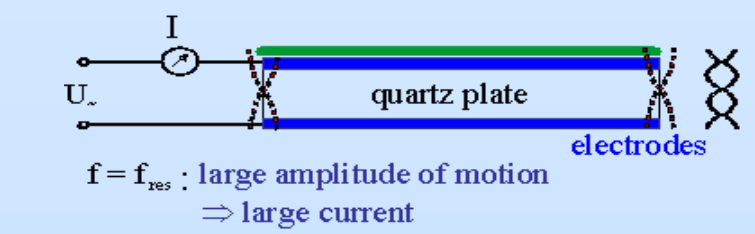


Fig 3. Aerosol Generation and the Wind Tunnel Recirculation Aerosol Chamber (WTRAC)

3. Quantitative Analysis of Iron (II,III) Oxide Particles Collected by the MPAS

- Gravimetric analysis using a Quartz Crystal Microbalance



Sauerbrey Equation

$$\Delta f = -C_f \Delta m$$

where

$$\Delta f = \text{the observed frequency change in Hz}$$
$$C_f = \text{the sensitivity factor for the crystal}$$
$$\Delta m = \text{the change in mass per unit area in g/cm}^2$$

- Atomic Force Microscope (AFM) or Scanning Electron Microscope (SEM) for Direct Counting

4. Development of a Deposition Velocity Model

Steady State Diffusion Equation

$$F = -(\epsilon_p + D) \frac{dC}{dz} + V_{ext} Ck$$

$$C_{\infty} = \frac{M}{A \cdot t \cdot V_{dep}} = \frac{F}{V_{dep}}$$

where M is the particles mass collected by the passive sampler, A is the sampling area of the MPAS, t is the sampling time for each test, and V_{dep} is deposition velocity

$$V_{dep} = \frac{-V_{ext} k}{\exp(I \times V_{ext} k) - 1} \quad \text{and} \quad I = \int_{\sigma}^{\delta} \frac{dz}{\epsilon_p + D}, \quad V_{ext} = \mu_0 \nabla(m_m \cdot H) \cdot \frac{24}{C_D Re} \cdot \frac{C_c}{3\pi \mu d_p}$$

where m_m is the magnetic moment of a particle, μ_0 is the magnetic permeability of free space, H is the magnetic field strength, C_D is the drag coefficient, Re is the particle Reynolds number, C_c is the slip correction factor, μ is the air viscosity, and d_p is particle diameter.

Results and Findings

1. Magnetic Field Intensity

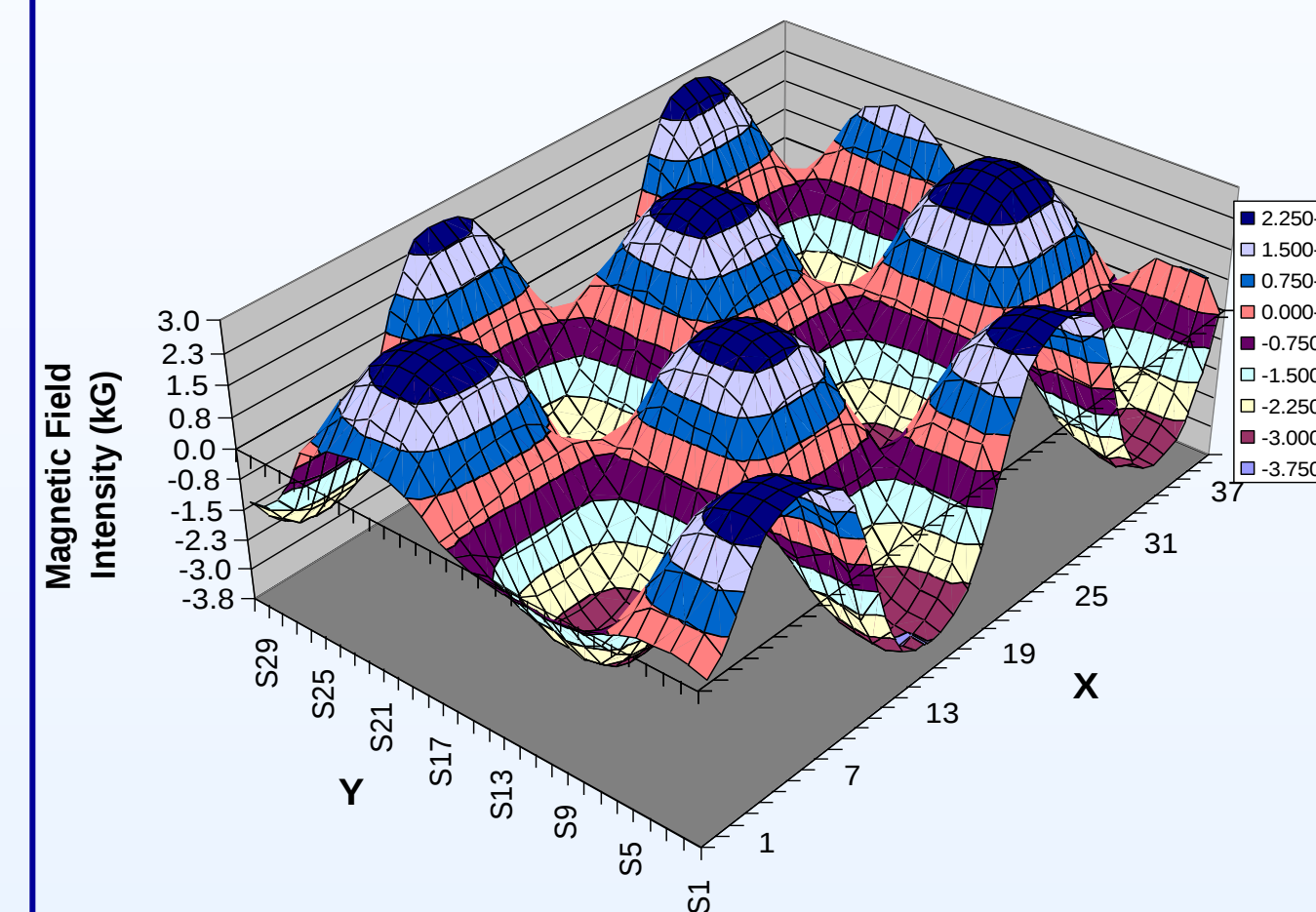


Fig 4. Magnetic Field Intensity Measured from a Representative Area Containing a Dozen Magnets by Using a Gaussmeter.

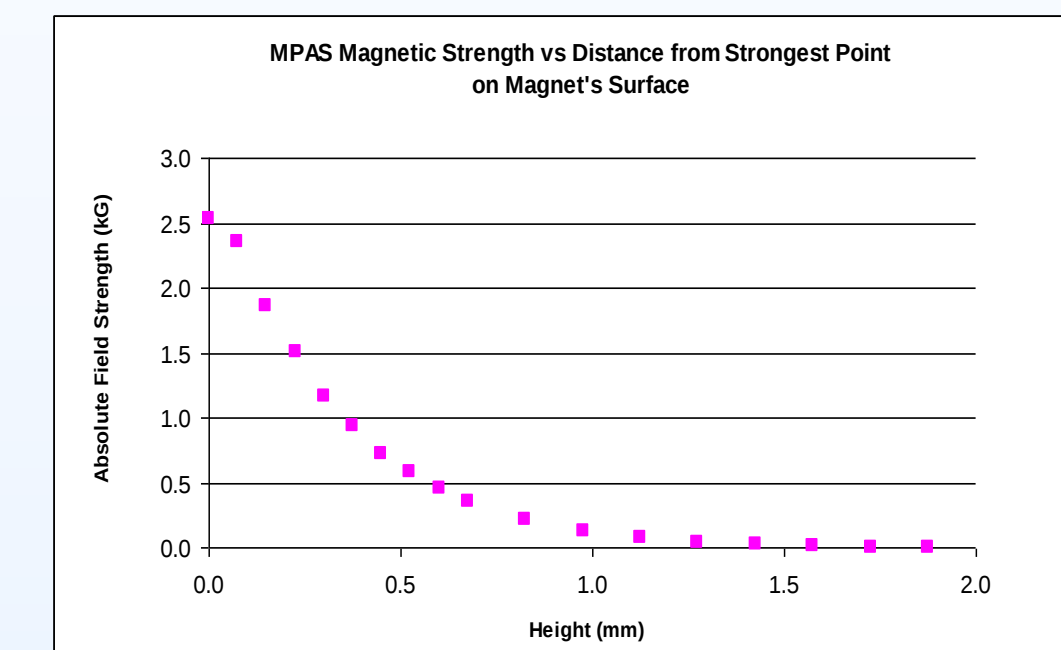


Fig 5. Magnetic Field Intensity vs. Distance from the Surface of the Multi-Domain MPAS

- The magnetic field created by the MPAS is quickly dissipated from the surface, thus it would avoid interfering with particle penetration through protective clothing.

2. Effect of Magnetic Field on Sampling Efficiency



(a) Without magnet, Loaded with polydisperse Fe₃O₄ for 2 hours



(b) With magnet, Loaded with polydisperse Fe₃O₄ for 2 hours

Fig 6. Collection Efficiencies of Passive Aerosol Samplers With and Without Magnetic Force

- The sampling efficiency of the MPAS is much higher and allowing for a shorter sampling time than a conventional passive sampler due to the additional magnetic force.

3. Iron (II, III) Oxide Detection

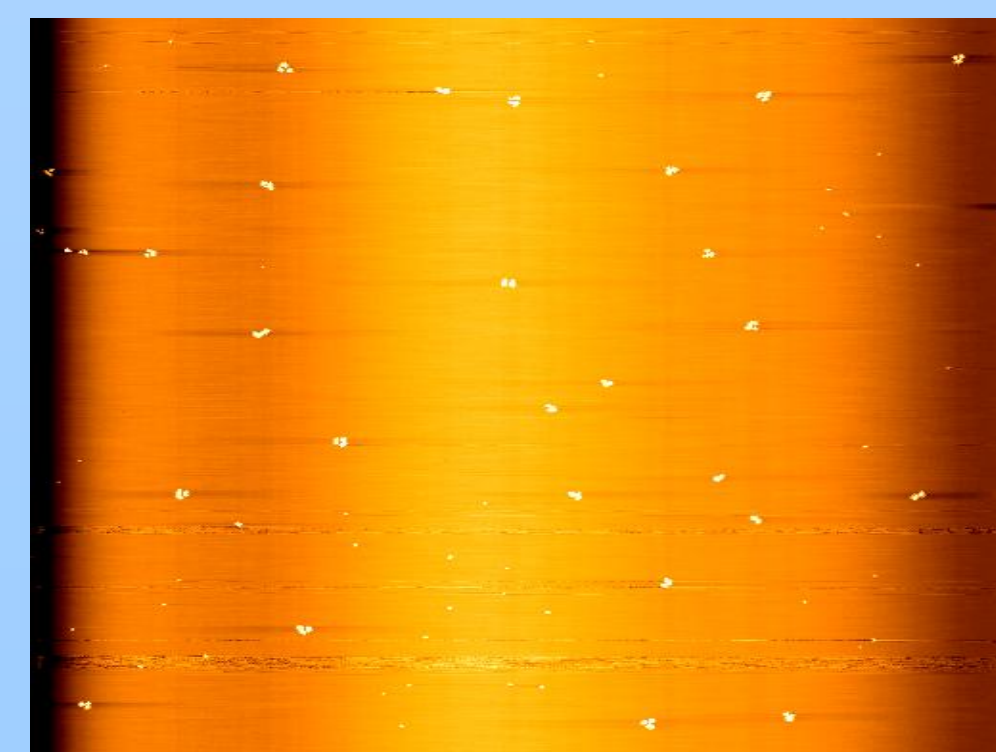


Fig 7. AFM Image of Iron (II, III) Oxide Particles Collected by the MPAS for Quantitative Analysis at Low Penetration

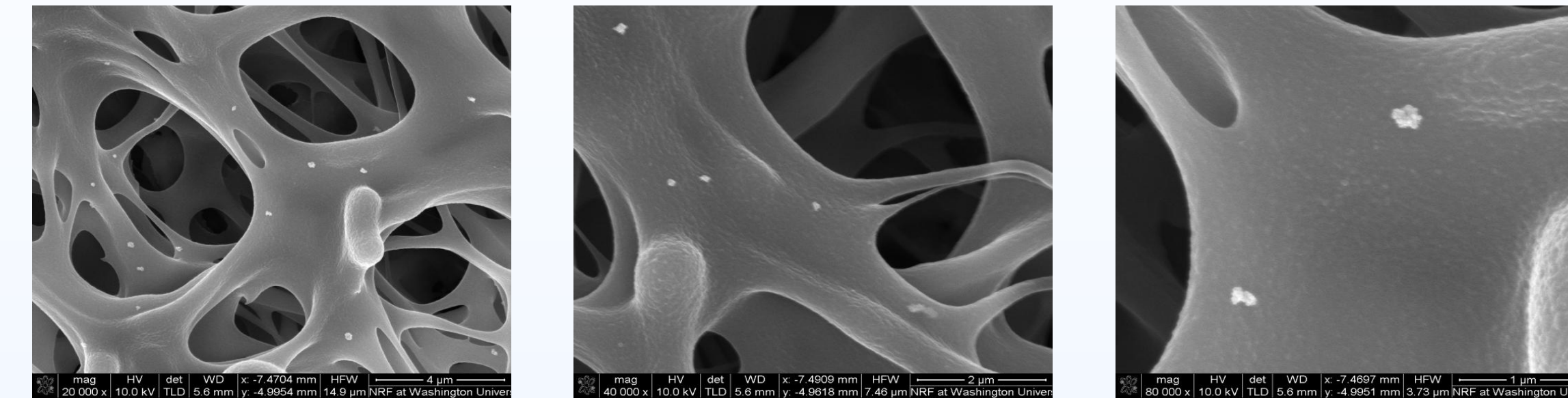


Fig 8. SEM images of Fe₃O₄ particles collected by MPAS using Teflon membrane filter as sampling substrate

- By using the QCM sensor crystal as the sampling substrate on the MPAS, the detection limit of the collected particle mass can be lowered to a few ng/cm². AFM or SEM can be used to determine particle penetration at lower values.

4. Velocity Profile of the WTRAC

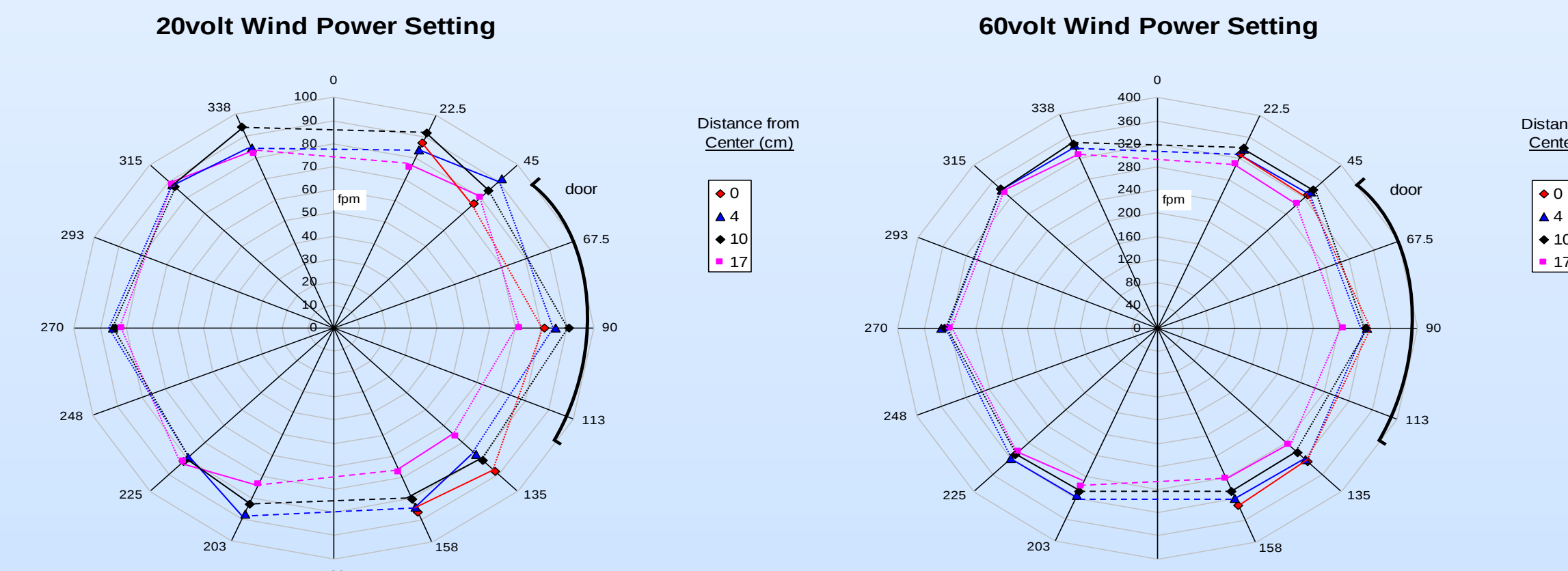


Fig 9. Axial velocity profiles of the test section (left shows 20 volts wind power setting, and right shows 60 volts wind power setting)

5. Spatial Distribution of Particles in the WTRAC

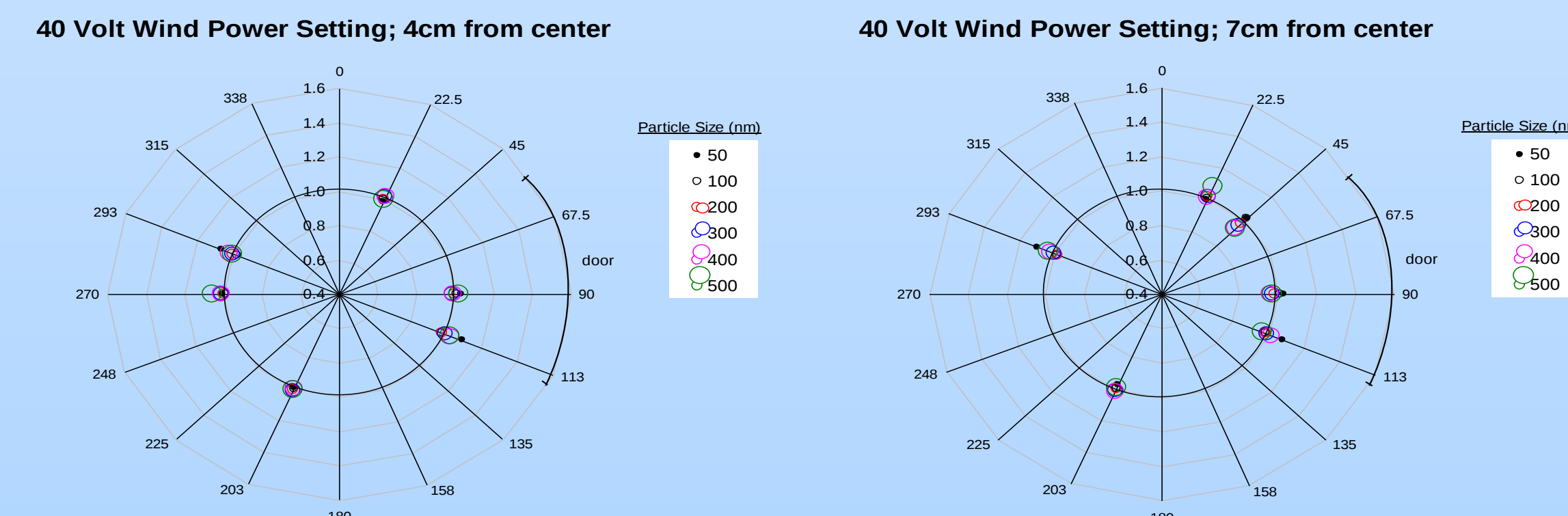


Fig 10. WTRAC spatial particle concentrations at 2 distances from the center normalized to the value at the center

- The velocity profile and the spatial distribution of particle concentration in the WTRAC are sufficiently uniform, which ensures the quality of replicate measurements inside the chamber.

Conclusions

- The MPAS prototype is potentially suitable for the MIST, because it samples passively, it has a compact design, and has a high sampling efficiency.

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